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Performance evaluation of half effect LiBr-H_2O vapour absorption systems using multi cascading of vapour compression cycles for low temperature applications

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Abstract

Most of the absorption cooling system use either LiBr-H_2O or NH_3-H_2O solutions. The LiBr-H_2O system can operate at a low generator temperature with better coefficient of performance than NH_3-H_2O system. However, COP of absorption system is relatively less as compared to the compression system. To improve its performances, several modifications have been made in the cycle. Therefore, this paper mainly deals with performance evaluations of half effect LiBr-H_2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications (at -100ºC) used for cryogenics applications and comparison at -50ºC evaporator temperature in the low temperature circuit using HFO refrigerants in the intermediate temperature circuit and found that half effect LiBr-H_2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications using HFC152a in intermediate temperature cycle and HFC-134a in LTC gives better thermodynamic performances than by using HFO refrigerants in intermediate temperature cycle & HFC-134a in low temperature cycle. The thermodynamic performances using HFO-1234ze in intermediate temperature cycle is better than using HFO-1234yf in intermediate temperature cycle.

Keywords: Multi-Cascade systems, Half effect LiBr-H_2O integrated absorption systems, HFO refrigerants

1. Introduction

Vapour absorption cooling systems are environmental, clean and economically driven refrigerating cycles. By consuming very small electric power, they can use waste heat or solar energy for cooling. The half effect absorption systems have the advantage of using low temperature heat energy for cooling. The first law & second law performances (i.e. coefficient performance (COP) and the exergetic efficiency) of the half effect absorption systems are found as 0.45 and 0.24, respectively. Arivazhagan R, et.al [1] computed component's irreversibilities and also are found most of the exergy destruction occurred in the evaporator and in the absorbers and concluded that the half effect absorption systems is the best for cooling driven by low temperature heat energy and the performance of the evaporator and the absorbers is very important for the cycle. In recent years, the fourth generation Hydrofluoro-olefins (HFOs)-R1234yf and R1234ze are being considered as alternative to R134a. A number of studies have been carried out using HFO 1234yf and HFO 1234ze. Although, R134a is a wide spread used refrigerant due to its commercial availability, similar properties to R12, less ODP value, excellent thermal stability, non toxic and non-flammability etc has high GWP value is more than 1300.

The European Union (EU) regulation is phasing out the current generation HFCs like R134a due to its high GWP and environment consequences. The thermodynamic and environmental characteristics of refrigerants HFC 134a, HFO 1234yf & HFO 1234ze are shown in Table-1.

The European Union (EU) regulation is phasing out the current generation HFCs like R134a due to its high GWP and environment consequences. A number of studies have been carried out using R1234yf and R1234ze [2]. In the notable studies [3-8], Yataganbaba et al. [3] performed exergy analysis on a two evaporator vapour compression refrigeration system using R1234yf, R1234ze and R134a as refrigerants. The two refrigerants R1234yf and R1234ze were good alternatives to R134a regarding their environment friendly properties.

Sanchez et al. [8] compared five low GWP refrigerants R152a, R1234yf, R1234ze, R290 and R600a for the replacement of R134a using hermetic compressor in the experimental test rig and

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found that the R1234yf and R152a can be considered suitable drop-in alternative to R134a by considering the energy consumption and the cooling refrigerating capacity of facility. Arora and Kaushik [9-10] developed then energy and exergy analysis of single effect and series flow double effect water–lithium bromide absorption system and found that the irreversibility is highest in the absorber in both systems as compared to other systems. Gomri [11] carried out thermodynamic analysis of single effect & double effect absorption refrigeration systems and found the COP of double effect system is approximately twice the COP of single effect system. S.B. Riffat N. Shankland [12] studied different types of absorption systems integrated with vapour-compression systems. Kilic and Kaynakli [13] carried out thermodynamic analysis for finding the performance of a single stage water lithium bromide absorption refrigeration system by varying inputs parameters and found that that the maximum energy loss occurs in generator of the system. Chinnappa et al. [14] proposed a compression-absorption cascaded refrigeration system which consist a conventional refrigerants with a solar operated, NH3-H_2O, VARS for air conditioning application. The above investigators have not carried out the performance evaluation for low temperature applications in cryogenics and the effect of performance parameters using HFO-1234yf in intermediate temperature circuit and HFC/134a in low temperature circuit. Therefore, this paper mainly deals with performance evaluations at -100°C used for cryogenics applications and comparison at -50°C evaporator temperature in the low temperature circuit using HFO refrigerants in the intermediate temperature circuit.

Table 1. Thermodynamic and environmental characteristics of refrigerants HFC 134a, HFO 1234yf & HFO 1234ze

Refrigerant	HFC 134a	HFO 1234yf	HFO 1234ze
Chemical Name	1,1,1,2-Tetrafluoroethane	2,3,3,3-Tetrafluoro-propene	trans-1,3,3,3-Tetrafluoro-prop-1-ene
Molecular formula	CH_2CF_4 (CF_3-CH_2F)	$C_3H_2F_4$ (CH_2=$CFCF_3$)	$C_3H_2F_4$ (CF_3CH=CHF)
Molecular mass (kg/kmol)	102.03	114.04	114.04
Boiling Point (^{0}C) at 1 atm	-26.07	-29.45	-18.95
Freezing Point (^{0}C) at one atm	-103.3	-150	-156
GWP Rating	1430	4	<1
ODP Rating	0	0	0
Appearance	Colourless	Colourless	Colourless
Combustibility	No	Yes (Low)	No
Critical Temperature (^{0}C)	101.06	94.69	109.37
Critical Pressure (MPa)	4.0593	3.3822	3.6363
Thermal stability	Excellent	Very good	Very good
Flammability	Non flammable	Mild flammable	Mild flammable

2. Results and Discussion

Following systems were chosen for numerical computation of integrated half effect LiBr-H_2O VARS multi cascaded VCRS for low temperature applications.

System-1

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and HFC-134a in cascaded vapour compression low temperature cycle

System-2

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and HFC-404a in cascaded vapour compression

System-3

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and HC-290 in cascaded vapour compression low temperature cycle

System-4

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and HC-600a in cascaded vapour compression low temperature cycle

System-5

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and HC-600 in cascaded vapour compression low temperature cycle

System-6

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFC-152a in Intermediate/Medium temperature vapour compression cycle and ethylene in cascaded vapour compression low temperature cycle

System-7

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and HFC-134a in cascaded vapour compression low temperature cycle

System-8

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and HFC-404a in cascaded vapour compression low temperature cycle.

System-9

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and HC-290 in cascaded vapour compression low temperature cycle

System-10

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and HC-600a in cascaded vapour compression low temperature cycle

System-11

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and HC-600 in cascaded vapour compression low temperature cycle

System-12

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234ze in Intermediate/Medium temperature vapour compression cycle and ethylene in cascaded vapour compression low temperature cyclcle.

System-13

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and HFC-134a in cascaded vapour compression low temperature cycle

System-14

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and HFC-404a in cascaded vapour compression low temperature cycle.

System-15

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and HC-290 in cascaded vapour compression low temperature cycle.

System-16

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and HC-600a in cascaded vapour compression low temperature cycle

System-17

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and HC-600 in cascaded vapour compression low temperature cycle

System-18

Half effect LiBr-H_2O vapour absorption refrigeration system using cascaded HFO-1234yf in Intermediate/Medium temperature vapour compression cycle and ethylene in cascaded vapour compression low temperature cycle

The following numerical values have been used for numerical computations.

(i) Generator temperature is 80oC (although it varying from 60^0C to 90^0C
(ii) Half effect vapour absorption refrigeration system evaporator temperature is 5^0C (although it varying from 1^0C to 10^0C).
(iii) Heat exchanger effectiveness is 0.5 (although it varying from 0.50 to 0.80).
(iv) Condenser temperature of half effect vapour absorption refrigeration system is 30^0C (although it varying from 30^0C to 40^0C.
(v) Temperature overlapping between HFO condenser and LiBr-H2O evaporator is 10 oC (although it varying from 0^0C to 15^0C)
(vi) Temperature overlapping between HC/HFC condenser and HFC/HFO evaporator is 10 ^{0}C (although it varying from 0^0C to 15^0C)

Table-2 (a) shows the effect of LTC refrigerants on thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for ITC evaporator temperature of -50ºC using HFC 152a and R134a in low temperature cycle (LTC) of -100ºC (system-1 to System-6) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the low temperature application as shown in table-2(b).

Table-3 (a) shows the effect of LTC refrigerants on performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for ITC evaporator temperature of -50ºC using HFO1234ze and R134a in low temperature cycle (LTC) of -100ºC (system-7 to System-12) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the low temperature application as shown in table-3(b).

Table-4 (a) shows the effect of LTC refrigerants on performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems for ITC evaporator temperature of -50ºC using HFO1234yf and R134a in low temperature cycle (LTC) of -100ºC (system-13 to System-18) and found that HFO refrigerants of low GWP gives better thermodynamic performances than HFC refrigerants and also gives better improvement in the thermodynamic performances. The lowest thermodynamic performances were observed by using ethylene in the low temperature application as shown in table-4(b).

Table-5, shows the comparison of thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems HFC-152a and HFO refrigerants in the intermediate temperature cycle for ITC evaporator temperature of -50ºC and R134a in low temperature cycle(LTC) of -100ºC (system-1, system-7 & System-13) and found that HFO refrigerants of low GWP gives lower thermodynamic performances than HFC-152a refrigerant and also gives better improvement in the thermodynamic performances.

Table-2(a): Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFC-152a in Intermediate temperature circuit and following systems for low temperature applications

Parameters	System_1 LTC_R134a	System_2 LTC_R404a	System_3 LTC_R290	System_4 LTC_R600a	System_5 LTC_R600	System_6 LTC_Ethylene
Cascade COP	0.7675	0.7606	0.7691	0.7693	0.7720	0.7443
$EDR_{Cascade}$	0.975	1.046	0.9598	0.9578	0.9314	1.230
Exergetic $Efficiency_{Cascade}$	0.5063	0.4887	0.5016	0.5108	0.5178	0.4484

Table-2(b) : % improvement in Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFC-152a in Intermediate temperature circuit and following systems for low temperature applications

Performance Parameters	System_1 LTC_R134a	System_2 LTC_R404a	System_3 LTC_R290	System_4 LTC_R600a	System_5 LTC_R600	System_6 LTC_Ethylene
% improvement in cascade COP	76.06	74.47	76.41	76.46	77.08	70.72
% decreasement $EDR_{Cascade}$	-77.46	-75.81	-77.81	-77.85	-78.47	-71.56
% improvement in $ExergeticEfficiency_{Cascade}$	169.6	160.3	171.7	172.0	175.7	138.8

Table-3(a): Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO-1234ze in Intermediate temperature circuit and following systems for low temperature applications,

Parameters	System_7 LTC_R134a	System_8 LTC_R404a	System_9 LTC_R290	System_10 LTC_R600a	System_11 LTC_R600	System_12 LTC_Ethylene
Cascade COP	0.7637	0.7569	0.7652	0.7654	0.7681	0.7407
$EDR_{Cascade}$	0.9379	1.065	0.9785	0.9764	0.9499	1.25
Exergetic $Efficiency_{Cascade}$	0.5016	0.4842	0.5054	0.5060	0.5128	0.4444

Table-3(b): % improvement in Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO-1234ze in Intermediate temperature circuit and following systems for low temperature applications,

Performance Parameters	System_7 LTC_R134a	System_8 LTC_R404a	System_9 LTC_R290	System_10 LTC_R600a	System_11 LTC_R600	System_12 LTC_Ethylene
% improvement in cascade COP	75.18	73.61	75.53	75.57	76.19	69.9
% decreasement $EDR_{Cascade}$	-77.02	-75.37	-77.38	-77.42	-78.04	-71.09
% improvement in Exergetic $Efficiency_{Cascade}$	167.10	157.8	169.2	169.4	173.1	136.6

Table-4(a): Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO-1234yf in Intermediate temperature circuit and following systems for low temperature applications,

Parameters	System_13 LTC_R134a	System_14 LTC_R404a	System_15 LTC_R290	System_16 LTC_R600a	System_17 LTC_R600	System_18 LTC_Ethylene
Cascade COP	0.7607	0.7539	0.7622	0.7624	0.7650	0.7378
$EDR_{Cascade}$	1.009	1.061	0.9935	0.9915	0.9648	1.266
Exergetic $Efficiency_{Cascade}$	0.4978	0.4806	0.5016	0.5021	0.5090	0.4412

Table-4(b): % improvement in Performance Parameters of Integrated half effect LiBr-H_2O VARS multi cascaded VCRS using HFO-1234yf in Intermediate temperature circuit and following systems for low temperature applications

Performance Parameters	System_13 LTC_R134a	System_14 LTC_R404a	System_15 LTC_R290	System_16 LTC_R600a	System_17 LTC_R600	System_18 LTC_Ethylene
% improvement in cascade COP	74.48	72.92	74.83	74.87	75.48	69.25
% decreasement $EDR_{Cascade}$	-76.68	-75.02	-77.03	-77.08	-77.69	-70.72
% improvement in Exergetic $Efficiency_{Cascade}$	165.1	155.9	167.1	167.4	171.0	135.0

Table-5: Comparison of Performance Parameters of three integrated half effect LiBr-H_2O VARS multi cascaded VCRS in Intermediate temperature circuit and following systems for low temperature applications using HFC-134a in LTC

Parameters	System_1 MTC_R152a	% improvement	System_7 MTC_R1234ze	% improvement	System_13 MTC_R1234yf	% improvement
MTC_COP	0.7116	63.22	0.7077	62.34	0.7047	61.64
$EDR_{Cascade}$	1.337	69.08	1.373	- 68.26	1.402	-67.60
Exergetic $Efficiency_{Cascade}$	0.4278	-127.8	167.1	124.4	0.4164	121.7

3. Conclusions

Following conclusions were drawn from present investigations.

(i) Thermodynamic performance of cascaded integrated vapour compression half effect LiBr H_2O absorption systems HFC-152a and HFO refrigerants in the intermediate temperature cycle for ITC evaporator temperature of -50ºC and R134a in low temperature cycle (LTC) of -100ºC (system-1, system-7 & System-13) and found that HFO refrigerants of low GWP gives lower thermodynamic performances than HFC-152a refrigerant and also gives better improvement in the thermodynamic performances.

(ii) Half effect LiBr-H2O vapour Absorption Systems using multi cascading of vapour compression cycles for low temperature applications using HFC152a in intermediate temperature cycle and HFC-134a in LTC gives better thermodynamic performances than by using HFO refrigerants in intermediate temperature cycle & HFC-134a in low temperature cycle.

(iii) The thermodynamic performances using HFO-1234ze in intermediate temperature cycle is better than using HFO-1234yf in intermediate temperature cycle.

(iv) The first law efficiency (COP_Cascade) of multi-cascade system increases with an increase with increasing evaporator temperature of vapour absorption refrigeration cycle.

(v) The second law efficiency (exergetic efficiency) of multi-cascade system decreases with an increase with increasing generator temperature of vapour absorption refrigeration cycle.

(vi) The second law efficiency (exergetic efficiency) of multi-cascade system decreases with an increase with increasing evaporator temperature of vapour absorption refrigeration cycle.

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